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DRP-3-07
November 1992

Dredging Research Technical Notes

Applying Electrical Resistivity Methods for Measuring Dredged Material Density in Hopper Bins

Purpose

This technical note provides information on the design, development, and testing of an electrical resistivity probe for measuring the vertical density profile of dredged material in hopper bins. It summarizes design, development, and laboratory proof-of-principle evaluations and documents prototype development and testing.

Background

The dredging industry needs accurate and reliable methods for directly monitoring and quantifying hopper bin loads. Currently, hopper loads are measured by relating the draft of the dredge to the dredged material weight in the hopper. This system measures hydrostatic pressure change as a function of draft and relates this change in draft to hopper load using the vessel weight/draft tables available from the shipyard. The load data are then used indirectly to calculate the average density in the hopper and, subsequently, the in-place yardage of material removed, accounting for dredging environment variables such as water and in-place sediment density.

The indirect method of determining hopper density is subject to error. For example, rough seas can adversely affect the measured draft of the vessel, adding a degree of error to the load calculation. The random uncertainty of the production calculation when using this system can approach 20 percent (Rokosch 1989).

Direct measurement of density in the hopper would result in reliable production data as well as a basis to describe how various types of dredged material will consolidate in the hopper. The only currently available technology capable of directly monitoring density profiles in dredge hoppers uses nuclear measurement principles. The major obstacles to

using these devices in or around the dredge hopper are regulatory and safety concerns.

The harsh hopper environment prohibits the use of automated mechanical profiling devices for obtaining density profiles. The resistivity probe concept consists of using a stationary nonnuclear device capable of withstanding the hostile hopper environment, with design and operation based on well-understood electrical current transmission and voltage measurement principles. This device may have the potential to provide a new technology for direct measurement of hopper load density and subsequent load calculation.

Additional Information

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Introduction

DRP work unit Technology for Monitoring and Increasing Hopper Dredge Payload for Fine-Grained Sediments is directed toward investigating new methodologies for monitoring and increasing hopper dredge productivity. The work unit has focused on better ways of measuring important dredge parameters such as using acoustic sensors for measuring dredge draft and hopper bin water volumes, which are essential to present-day methods of measuring dredge production.

Directly monitoring dredged material density in the hopper during the dredging cycle has the greatest potential for improving the monitoring of hopper dredge payload. To address this problem, innovative equipment capable of withstanding the hopper environment had to be developed.

In previous studies, the electrical resistivity principle demonstrated promise for measuring fluid mud density in navigation channels. Based on those findings, efforts were undertaken to develop an electrical resistivity probe for measurement of sediment densities in dredge hoppers. The development included three phases: proof-of-principle laboratory studies, design and fabrication of a prototype dredge hopper probe, and field test and evaluation. This technical note describes the probe development and the initial field tests.

Electrical Resistivity Concept

Electrical resistivity techniques are commonly used in geophysical explorations. Basically, geophysical electrical resistivity studies involve the measurement of potentials, currents, or electromagnetic fields that are

introduced into the earth. Properties of subsurface materials can be determined by the variation in these measurements due to change in the electrical conductivity through the materials. The electrical resistivity of most soil minerals is so high that most electrical current flow through a soil will be through the soil pore water. For this reason, the bulk resistivity of a soil sample will depend mainly on the amount and resistivity of the water contained in the sample, although clay exhibits some surface conduction effects and often displays a different bulk resistivity than other minerals.

Density measurements using the resistivity principle involve introducing a current source through electrodes into a medium and measuring the potential across electrodes within the vicinity of current flow. The resistivity is defined as a function of input current, measured potential, and electrode configuration. For the resistivity probe developed during this study, the Wenner electrode array was used (Telford and others 1976). This array consists of four evenly spaced electrodes in a line. Current is introduced into two outer electrodes, and the potential is measured between two inner electrodes. Figure 1 shows a schematic of the Wenner array and the resulting electric field that is generated. The apparent resistivity, ρ_a, measured by this electrode arrangement is defined as:

$$\rho_a = 2\pi a \frac{\Delta V}{I}$$

where $2\pi a$ is defined as the geometric factor based on the electrode array spacing, a, and the geometry of the equipotential surface and current flow lines.

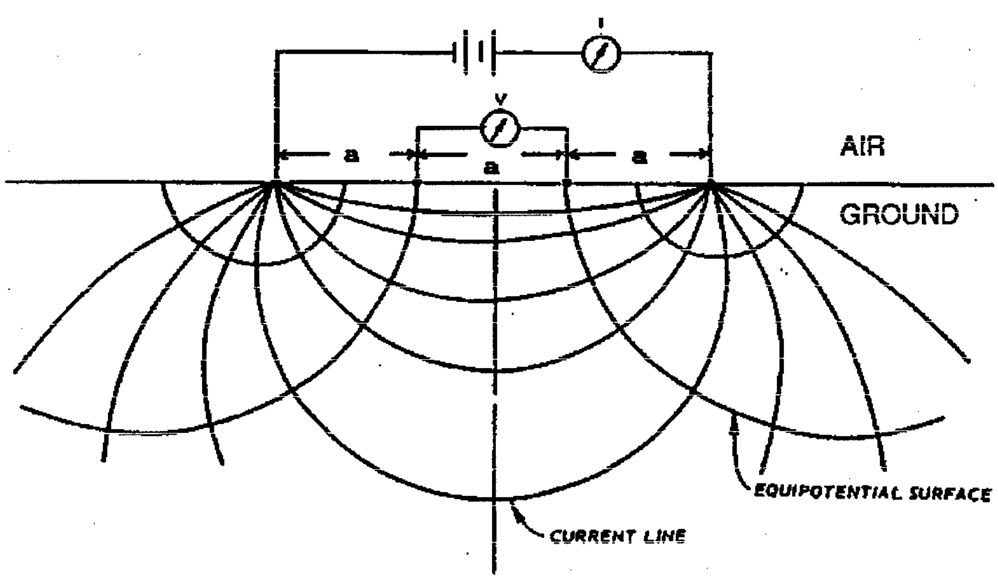

Figure 1. Wenner electrode array for making resistivity measurements (notations defined in text)

The value of ΔV is the potential change across the inner electrode pair, and I is the current input into the medium through the outer electrode pair.

Laboratory Resistivity Studies

To evaluate the resistivity principle, a laboratory-scale resistivity test cell was developed under contract. This probe consisted of 24 electrodes spaced 1 in. apart, imbedded in polycarbonate plastic (Figure 2). The electrodes consisted of stainless steel screw heads. Each electrode was wired to a connecting cable interfaced with a switch box, which was used to select the current input and voltage measurement electrodes.

The purpose of the laboratory tests was to determine whether the vertical density profile of suspended and settled sediments could be accurately determined using electrical resistivity measurements. To support the laboratory resistivity probe tests, a calibration probe and related instrumentation were also developed.

Calibration tests with a variety of sediment types (sand, silt, and clay) in homogeneous and mixed sediment suspensions resulted in a series of empirically based calibration curves describing sediment density as a function of formation factor (Figure 3, 4, and 5). The formation factor is defined by the bulk resistivity measurement (given in the earlier equation) divided by the resistivity of the water in the slurry. The formation factor

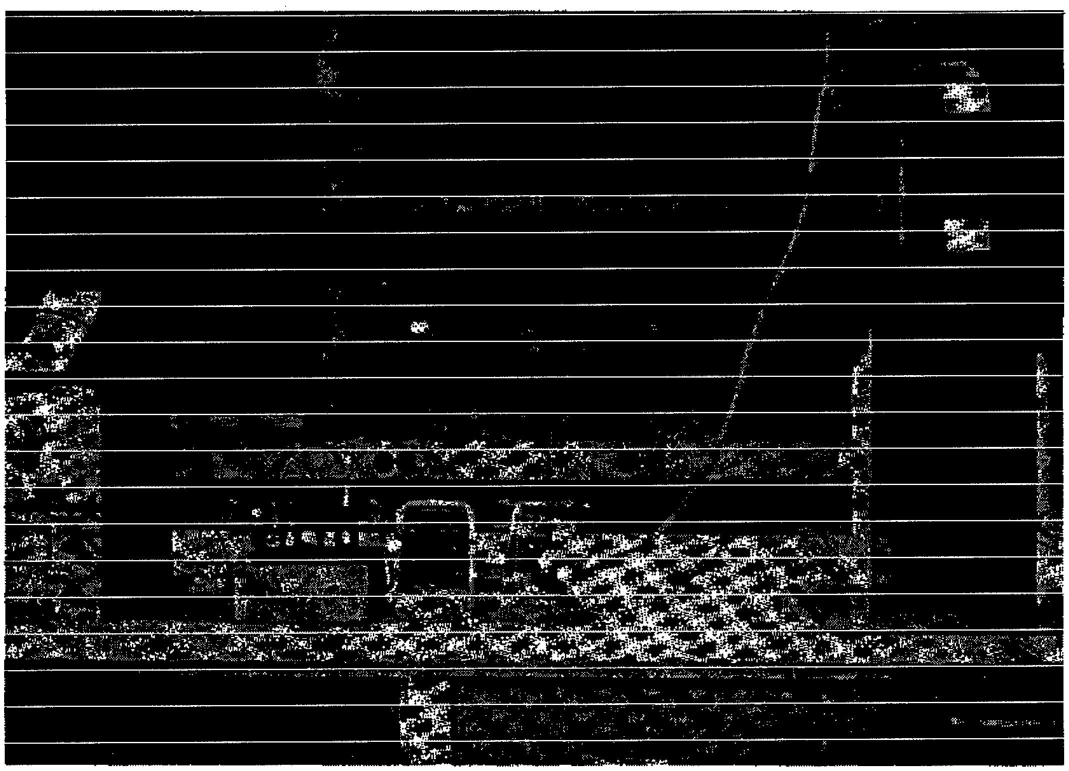

Figure 2. Laboratory-scale resistivity probe and calibration cell

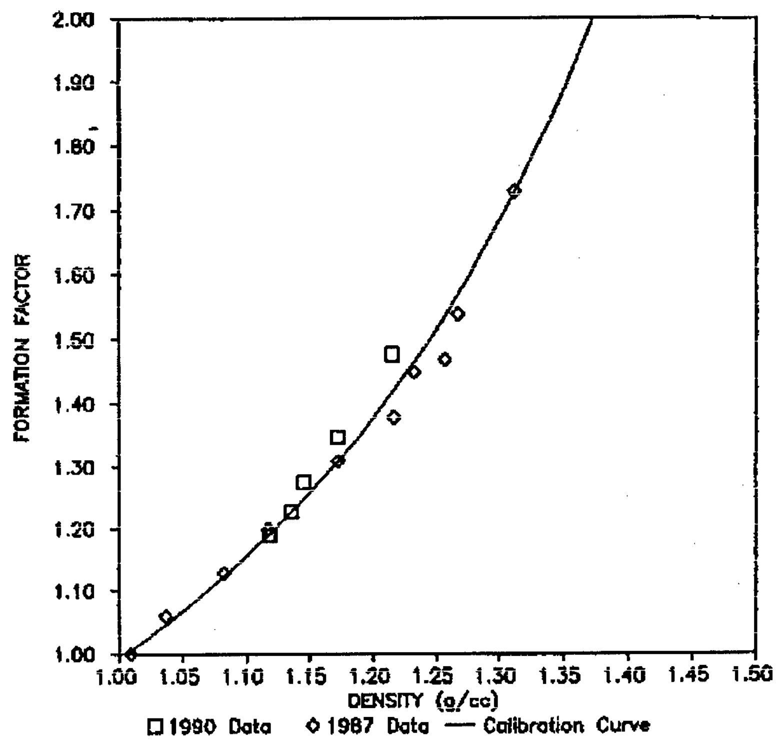

Figure 3. Bentonite clay calibration curve

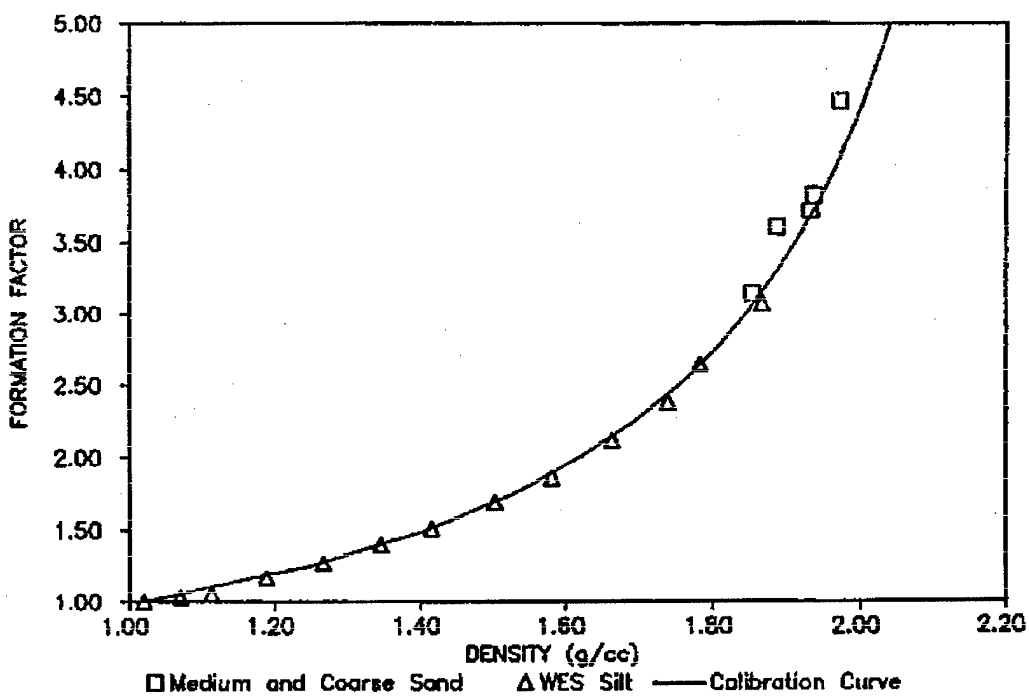

Figure 4. Sand and silt calibration curve

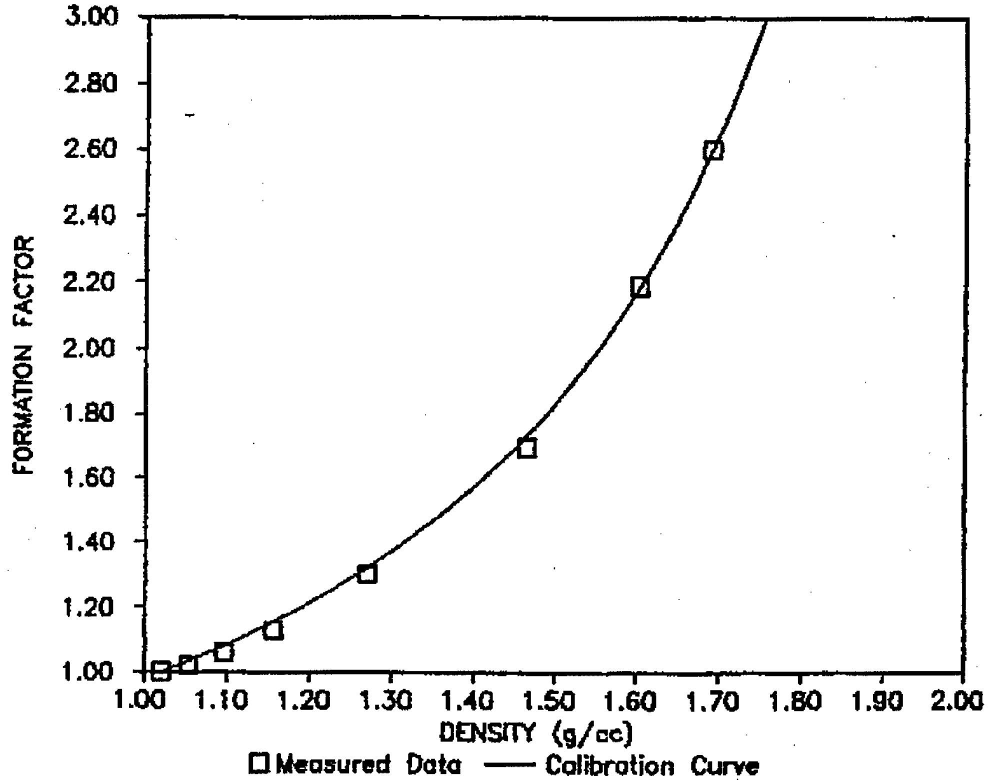

Figure 5. Mixed sand/silt/clay calibration curve

normalizes the resistivity-density relationship to any environmental water resistivities encountered (fresh or saline waters). The laboratory probe was filled with various sediment mixtures, and density profiles were measured using the appropriate calibration curves.

The results of these tests for the sand/silt/clay mixture are given in Figure 6. Density profiles were obtained after several intervals of time to show the consolidation of the sediments as settling occurred. Just after mixing, the sediments remained suspended. With time, the fines remained in suspension and the coarse sand settled to the bottom. Analysis of data resulting from the laboratory study indicated that the resistivity method produced accurate, repeatable density profiles and that a full-scale resistivity probe should be developed based on these findings.

Prototype Resistivity Probe Development

Based on design parameters determined from the laboratory studies, a prototype resistivity probe was designed and constructed under a continuation of the laboratory study contract. The probe was designed for installation in the hopper of the dredge *Wheeler* operated by the U.S. Army Engineer District, New Orleans. The probe was designed to profile the entire depth of the hopper, requiring a 40-ft probe length. Forty electrodes

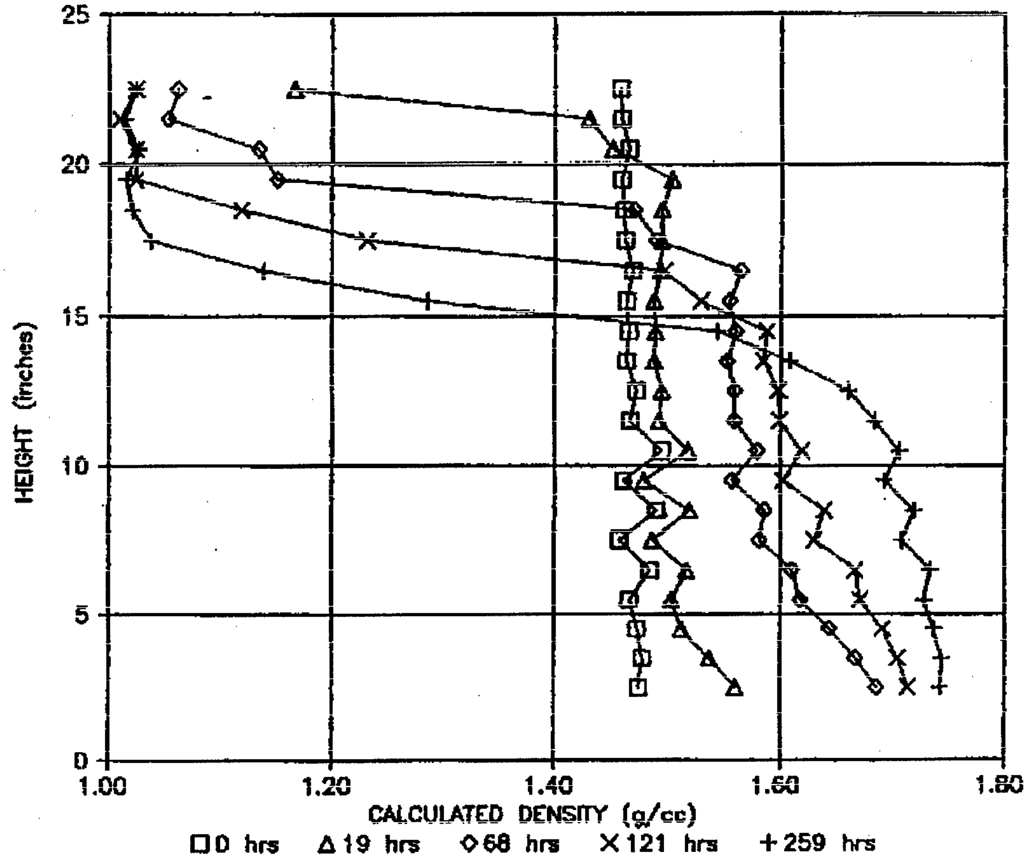

Figure 6. Laboratory resistivity probe test results for a sand/silt/clay mixture

were required, spaced at 1-ft intervals. The electrodes consisted of stainless steel hose clamps. The probe body was constructed of ten individual 4-ft segments of 0.75-in.- diam plastic pipe. All electrodes were hard wired, with the wire bundle sealed inside the pipe segments. The individual electrode connections were connected to a switch box for manual profiling of the probe. The probe was mounted on one side of a 42-ft-long, epoxy-filled fiberglass mounting beam (Figure 7). The noncorrosive structural beam has strength properties of steel, with less than half the weight of steel.

Prototype Probe Installation and Testing

The resistivity probe was installed in the hopper of the dredge *Wheeler* during shipyard maintenance. Mounting locations in the hopper were determined from previous visits to the dredge while in operation, so the mount could be positioned in a location with minimal turbulence, offering more protection for the probe. The probe was mounted on steel mounting brackets attached to structural members in the hopper (Figure 8). The cable was run to accompanying instrumentation located in a remote area away from the hopper.

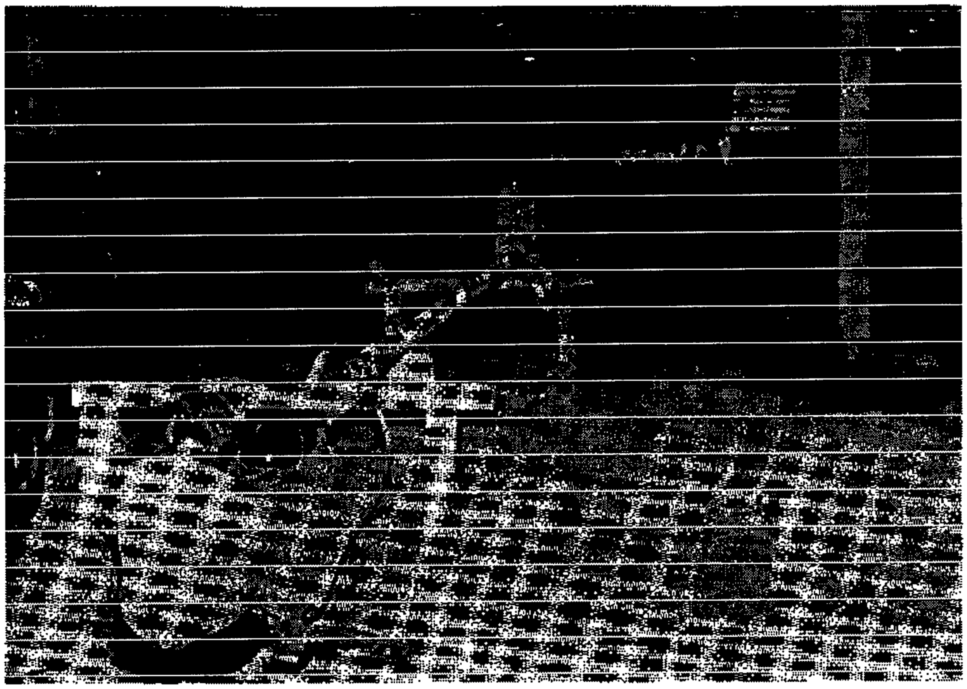

Figure 7. Prototype resistivity probe attached to the fiberglass mount

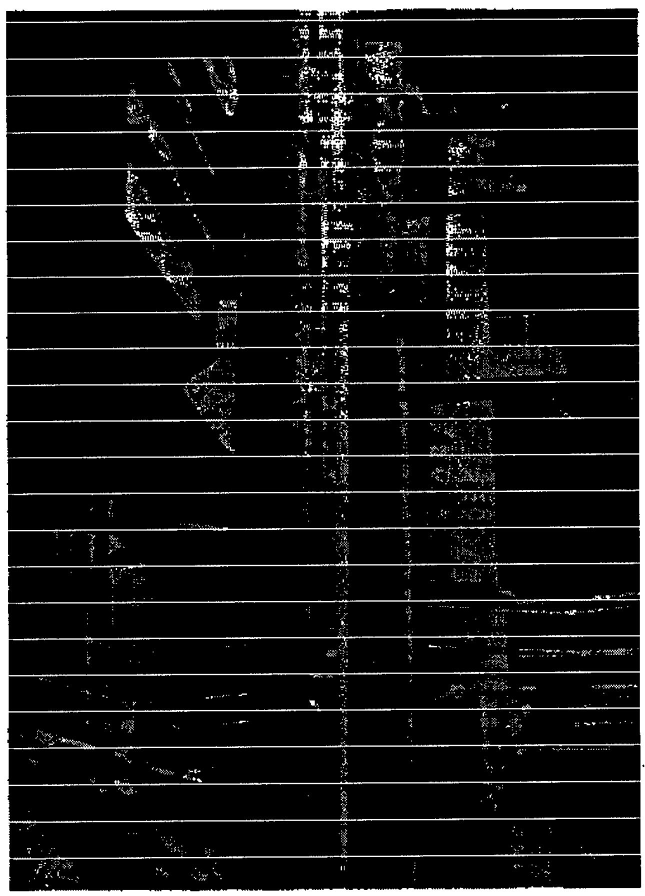

Figure 8. Resistivity probe installed in the hopper of the dredge *Wheeler*

Field tests of the prototype probe were conducted when the dredge was operating at the mouth of the Mississippi River in the Head of Passes area. Analysis of sediment samples taken at this location indicate a composition of approximately 59 percent coarse materials by weight (>63 microns) and 41 percent of fine materials by weight (<63 microns). The laboratory calibration curve generated for a sand/silt/clay mixture (Figure 5) was chosen for this particular sediment.

Initially, the water resistivity was measured for calculation of the formation factor. Then resistivity data were collected on successive dredged material loads in the hopper. Production meter densities were also recorded during the tests to determine the average density of material flowing into the hopper as a comparison.

Density profiles in the *Wheeler* hopper measured with the resistivity probe are depicted in Figure 9. Each curve on the graph represents a point in time during the dredging cycle, from the point of overflowing the weirs to arrival at the disposal site. The Y-axis on the graph represents the depth in the hopper, with 42 ft being the top of the overflow weirs. The lower end of the probe was attached at the bottom of the hopper approximately 8 ft above the hopper doors. The graph indicates that the material consolidated as a function of time in the hopper, even though a relatively high concentration of silt-size material was present. The average density in the hopper as measured by the resistivity probe was within 5 percent of that measured by the nuclear density gauge on the production meter.

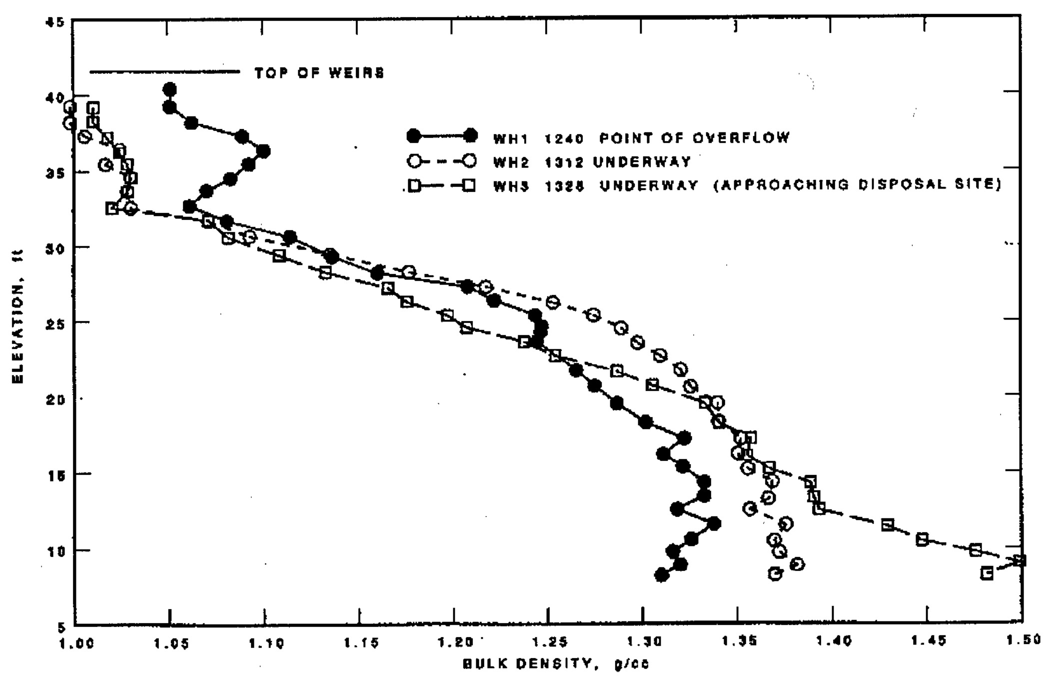

Figure 9. Resistivity probe density profiles for a hopper load from the dredge *Wheeler* (Load A, February 12, 1992)

Conclusions

This study has shown that the resistivity method has high potential for measuring the density of dredged material in hopper bins. Sediment density as a function of formation factor (sediment bulk resistivity divided by the water resistivity) was empirically derived in comprehensive laboratory tests. Subsequent prototype development and testing in actual hopper bins demonstrated the applicability of using the laboratory-generated data for calculating dredged material densities.

The development of this technology represents a significant improvement in several areas. The method is nonnuclear and thus presents no safety hazards. The prototype probe has proven its durability in an 8,000-cu yd hopper. Because of the basic design and operation of the resistivity probe, it is a low-maintenance and economical method for monitoring dredged material characteristics in the hopper.

At this phase of development, two operating characteristics must be improved before the resistivity method can be of practical use to dredge operators. Currently, the probe is manually profiled by using a selector switch to choose each individual electrode array for measurement. To improve the efficiency and speed of measurement, an automated method of profiling the probe and acquiring data is needed. Computer technology must be interfaced with the probe for data acquisition and analysis and for graphical display of the density profiles.

The use of the probe for monitoring the density profile in the hopper provides the dredge operator with a graphical record of dredged material density characteristics in the hopper during all phases of the dredging cycle. During overflow operations, the density profile can be monitored in the hopper at any time with the system. This would inform the operator of the level of the material in the hopper, the density of the overflow, and the rate of consolidation of solids in the hopper during overflow. For hopper dredges with adjustable weirs, the system could inform the operator of the depth to which the weirs could be lowered, based on the stratification of density in the hopper, for increasing the solids load in the hopper.

Acknowledgements

The execution of this study was made possible by access to the dredge *Wheeler*. Assistance was provided by the Dredge Management Section, Dredging Operations, U.S. Army Engineer District, New Orleans, in the implementation and testing of the resistivity probe. This technical note summarizes DRP work performed by Dr. Robert F. Corwin under Contract Nos. DACW 39-90-M-3831 and DACW 39-91-C-069 and reported to the DRP in two unpublished reports.

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